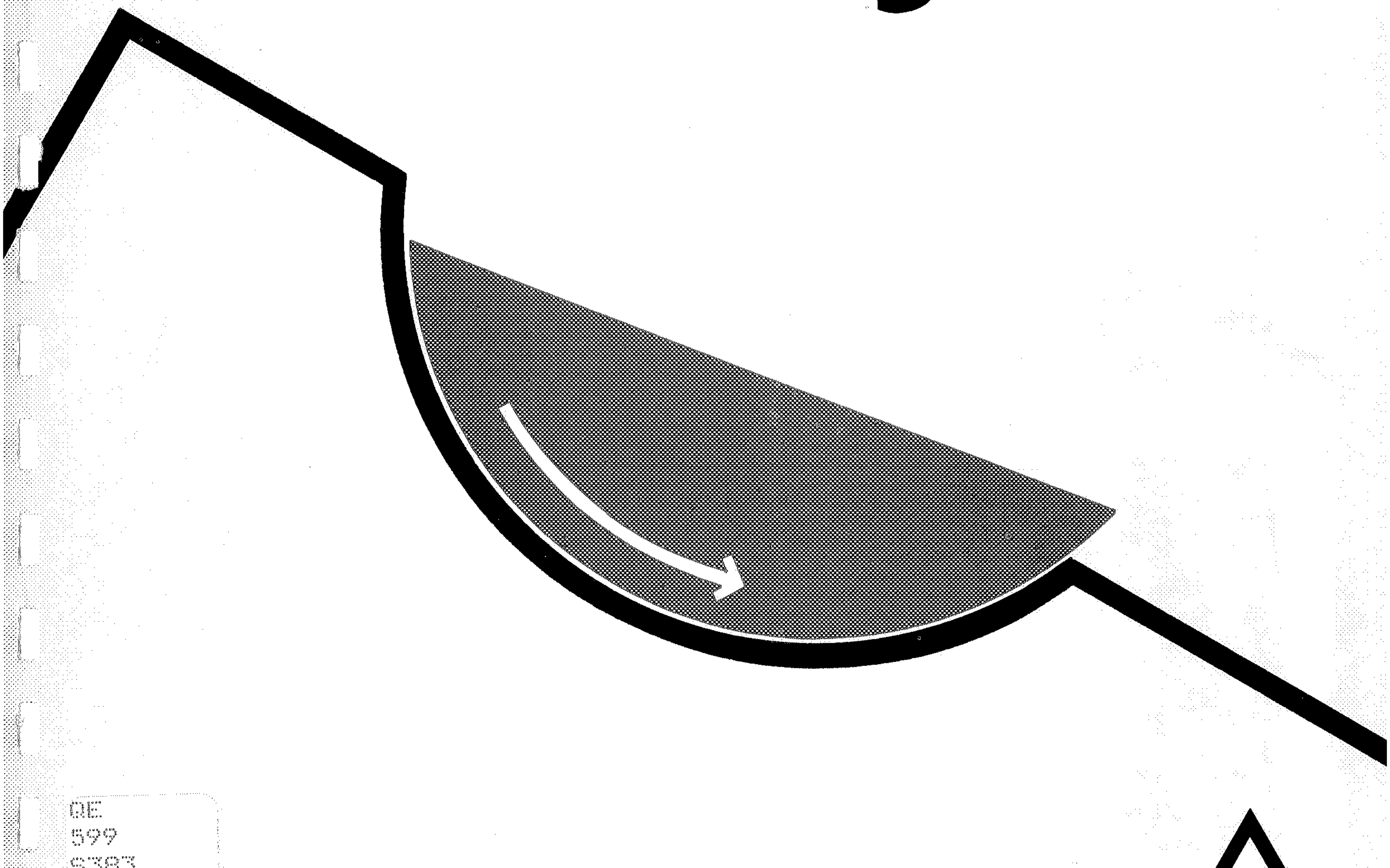
January 1976

Introductory Statement
Landslide Investigation



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SANTA CLARA VALLEY WATER DISTRICT

LANDSLIDE INVESTIGATION

AN INTRODUCTORY STATEMENT

by

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FOREWORD

This introductory statement discusses the significance of the real and potentially hazardous effects of landslides on the District's facilities and their operation. It places into perspective the relative importance of the natural geologic setting, geologic processes, and man's activities as they affect the stability of slopes and landslides.

Watershed areas tributary to reservoirs and lands adjacent to canals are under increasing pressure for residential and recreational development. This introductory statement points out possible hazards to property and persons, and makes preliminary recommendations regarding them.

In addition to this introductory statement, the landslide study is presented in separately bound sections for each of the following facilities: Almaden, Anderson, Calero, Coyote, Guadalupe, Lexington, and Stevens Creek Reservoirs; Almaden-Calero, Coyote, Coyote-Alamitos, and Coyote Extension-Evergreen Canals. Landslide maps and descriptions of selected landslides are included and specific recommendations are made in regard to each of these facilities.

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Bound Separately

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Reconnaissance of Landslide Conditions Along Coyote-Alamitos Canal

Reconnaissance of Landslide Conditions Along Coyote Extension-Evergreen Canal

INTRODUCTION

The hilly areas of Santa Clara County are from a geologic standpoint, inherently unstable. Numerous landslides, active and inactive, are found in the area. Recognizing the potential for problems to District facilities by landslides, the Santa Clara Valley Water District initiated a study of landslides and related problems along and adjacent to its canals and reservoirs. This study was conducted by District Engineering Geologists and the results are presented in separate reports for each water supply facility. A general discussion of the geologic setting and potential problems is contained in this volume.

Landslides as interpreted in this study refer to the downward and outward movement of slope forming materials composed of natural rock, soil, artificial fill, or combinations of these materials (Eckel, E.B., ed., 1958). Although surface soil creep in a strict sense is not considered a landslide, this phenomenon is included as part of this study, but only where "excessive" creep was observed. For the purpose of this study, soil creep is defined as the process whereby the upper few feet of soil moves slowly downslope (inches per year or less). Creep is the result of a combination of the force of gravity, the soil characteristics and the seasonal wetting-drying process. Nearly all sloping soils within the study area are affected by soil creep. "Excessive" soil creep is when the process has accelerated to the point where physical evidence exists such as hummocky slopes or leaning trees and fences. In areas of excessive creep there is the potential for damage to structures.

The landslide conditions were investigated at the following reservoirs: Almaden, Anderson, Calero, Coyote, Guadalupe, Lexington, and Stevens Creek; and the following Canals: Almaden-Calero, Coyote, Coyote-Alamitos, and Coyote Extension-Evergreen. Landslide maps, description of landslide conditions, and specific recommendations for each facility are presented in separate reports.

The purpose of the reports is to place into perspective construction and operation of reservoirs and canals and how they relate to the prevailing natural geologic environment and processes.

The documentation and findings of this study may also serve as an aid to planners, public agencies, developers and to utilities by pointing out the risks and hazards involved in developing on landslide areas near District facilities.

Objectives of Study

The objectives of the landslide study are to identify and evaluate the possible effects of landslides:

1. On dams and appurtenances, canals, pipelines, structures, and service roads.
2. On reservoir operation.
3. To public safety.
4. On public and private improvements near District facilities (subdivisions, recreational developments, roads, pipelines, recreational homes, and other improvements), and to suggest conditions under which improvements within the reservoir areas

and adjacent canals could be undertaken, whether by the District, other public agencies, or by private developers.

The objectives of the study are met largely through documentation of presently existing landslide conditions. Descriptions and areal mapping of landslides can serve as a basis for taking remedial action if necessary upon short notice. The nature of remedial action necessary for any particular slide would depend upon the current and historical nature and condition of the slide.

This study also acts as a point of reference for as yet unknown future needs. The documentation of landslide conditions therefore serves as a reference point to aid in determining slide activity or changes of activity over a period of time. This documentation may become increasingly more important for the purposes of reservoir and canal operation, and will provide a factual base from which information for future studies may be obtained. Oftentimes, portions of inactive old landslides become active or new landslides form due to a disturbance of the quasi-equilibrium condition of the soil mass by natural processes, by man's activities, or both. An ability to distinguish between causes or a combination of causes of landslide activity may very well become critical in the District's decision making process.

Scope of Study

This study is to be considered reconnaissance in scope, with more detailed inspection of only local problem areas. Use was made of available published and unpublished geologic maps and reports. In some of the more critical problem areas, a monitoring phase of the study has been initiated which will be sustained beyond the completion of this study.

This study included:

1. Interpretation of surface features and landslides by utilizing available aerial photographs with stereo coverage.

2. Reconnaissance geologic mapping of the study areas within the District's right of way and, in some instances, outside the right of way, with notations of landslide conditions observed. Mapping was done on maps at scales ranging from 1 inch equals 200 feet to 1 inch equals 2,000 feet. These maps are on file in the District office and are available for inspection. The data from these maps were reduced and are presented in individual sections of this report on 1 inch = 500 feet scale photomosaics.

3. Detailed geologic mapping in areas where active slides warranted closer inspection.

4. Establishing survey networks in two of the larger active landslides in the Anderson Reservoir area. These are monitored periodically to determine the rate of movement of the slide mass.

5. Inclinometer installations and monitoring at two locations within an active slide located near the upstream end of the outlet structure at Anderson Dam. The purpose of these installations is to determine the depth of the slide and its rate of movement in order to assess any hazard that might exist to the outlet structure should the slide mass move into the reservoir.

GEOLOGIC SETTING

Regional Geology, A Setting for Landslides

Nearly all of the District's reservoirs are located within the mountainous or foothill areas of Santa Clara County, either in the Santa Cruz Mountains on the west side of Santa Clara Valley or in the Diablo Range on the east side. The canals are located along the margins of the valleys in the foothill areas. The slopes of the mountainous areas are relatively steep in the upland areas becoming more gentle along the edges of Santa Clara Valley. Major structural features (faults, bedding strike, axis of folded beds) and topographic features (mountain ridges and valleys) trend northwesterly. Refer to Plate 1 for a regional geologic map and locations of District facilities.

Bedrock formations in the mountainous areas include the following (oldest to youngest):

1. Franciscan Group: This group consists of intensely folded, sheared, and faulted sedimentary, volcanic, and metamorphic rocks which are subject to deep weathering.

2. Serpentine: This formation is an igneous unit which intruded into the Franciscan Formation and is highly sheared and faulted.

3. Cretaceous and Tertiary Sedimentary Formations: These formations consist of well-bedded and folded shales and sandstones.

The following younger formations occur in the foothills overlying the bedrock formations (oldest to youngest):

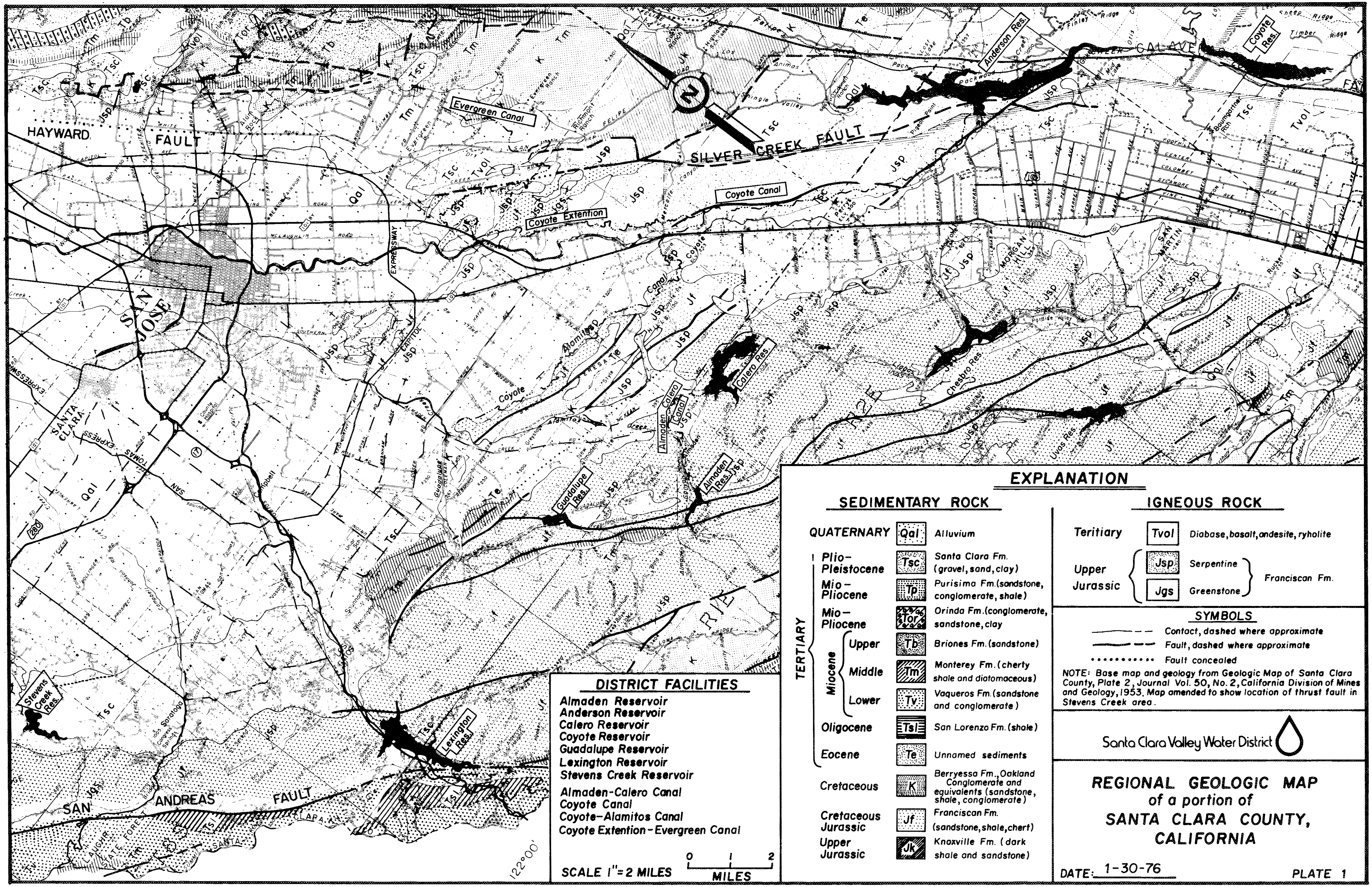
1. Santa Clara Formation (referred to as Packwood Formation at some locations): This formation consists of compacted to loosely consolidated alluvial beds of clayey sand, clayey gravel, and silty clay; beds are gently folded; it has fairly widespread distribution over the foothill areas and may attain considerable thickness.

2. Terrace Deposits: This formation consists of unconsolidated to compacted alluvial materials; it has small local distribution and is usually of limited thickness.

3. Alluvium: This formation consists of unconsolidated alluvial materials deposited along mountain valleys and streams. It has limited thickness and distribution in mountainous and foothill areas. However, this formation covers a large portion of the floor of Santa Clara Valley where it attains considerable thickness.

Landslides can occur in any unit in any one of the formations in the mountainous and foothill areas. However, formations which are particularly susceptible to landsliding are the Franciscan Formation, Serpentine, and the Santa Clara Formation. Formations more susceptible to sliding are soft and/or intensely sheared and deeply weathered. Due to the widespread distribution of these more susceptible formations in the mountainous and foothill areas, old and new landslides are prevelant in Santa Clara County.

Both active and inactive faults occur in the study area. Active faults cut through all formations while inactive faults occur in the bedrock formations and possibly in the Santa Clara Formation and do not offset the youngest formations.



DISTRICT FACILITIES

- Almaden Reservoir
- Anderson Reservoir
- Calero Reservoir
- Coyote Reservoir
- Guadalupe Reservoir
- Lexington Reservoir
- Stevens Creek Reservoir

- Almaden-Calero Canal
- Coyote Canal
- Coyote-Alamitos Canal
- Coyote Extention-Evergreen Canal

SCALE 1" = 2 MILES

0 1 2
MILES

EXPLANATION

SEDIMENTARY ROCK

QUATERNARY		Qal	Alluvium
TERTIARY	Plio-Pleistocene	Tsc	Santa Clara Fm. (gravel, sand, clay)
	Mio-Pliocene	Tp	Purisima Fm. (sandstone, conglomerate, shale)
	Mio-Pliocene	Tor	Orinda Fm. (conglomerate, sandstone, clay
	Miocene Upper	Tb	Briones Fm. (sandstone)
	Miocene Middle	Tm	Monterey Fm. (cherty shale and diatomaceous)
	Miocene Lower	Tv	Vaqueros Fm. (sandstone and conglomerate)
	Oligocene	Tsl	San Lorenzo Fm. (shale)
	Eocene	Te	Unnamed sediments
Cretaceous		K	Berryessa Fm., Oakland Conglomerate and equivalents (sandstone, shale, conglomerate)
Cretaceous Jurassic		Jf	Franciscan Fm. (sandstone, shale, chert)
Upper Jurassic		Jk	Knoxville Fm. (dark shale and sandstone)

IGNEOUS ROCK

Teritiary	Tvol	Diabase, basalt, andesite, ryholite	
Upper Jurassic	Jsp	Serpentine	Franciscan Fm.
	Jgs	Greenstone	

SYMBOLS

——— — —	Contact, dashed where approximate
━━━ ━ ━	Fault, dashed where approximate
··········	Fault concealed

NOTE: Base map and geology from Geologic Map of Santa Clara County, Plate 2, Journal Vol. 50, No. 2, California Division of Mines and Geology, 1953. Map amended to show location of thrust fault in Stevens Creek area.

Santa Clara Valley Water District

REGIONAL GEOLOGIC MAP
# of a portion of
SANTA CLARA COUNTY, CALIFORNIA

DATE: 1-30-76

PLATE 1

Major active faults include the San Andreas fault which trends northwesterly through the Santa Cruz Mountains and the Calaveras-Hayward fault system which trends northwesterly through the Diablo Range. The larger of the minor possibly active faults include: a) the Sargent-Berrocal fault in the Santa Cruz Mountains, b) the Shannon fault in the foothills of the Santa Cruz Mountains and along the western edge of Santa Clara Valley, c) the Silver Creek fault in the Diablo Range, and d) the Coyote Creek fault in the foothills of the Diablo Range.

Due to the intense shearing and deep weathering that is found within the fault zones, numerous slides occur along them. This is particularly true along the large active fault zones. Ground displacement and seismic shaking related to fault movement have provided the triggering mechanisim for a number of large and small landslides. Periodic fault movements and landsliding are natural geologic processes which have been occurring from the geologic past to the present and will continue into the future.

Types, General Description and Recognition of Landslides in the Study Area

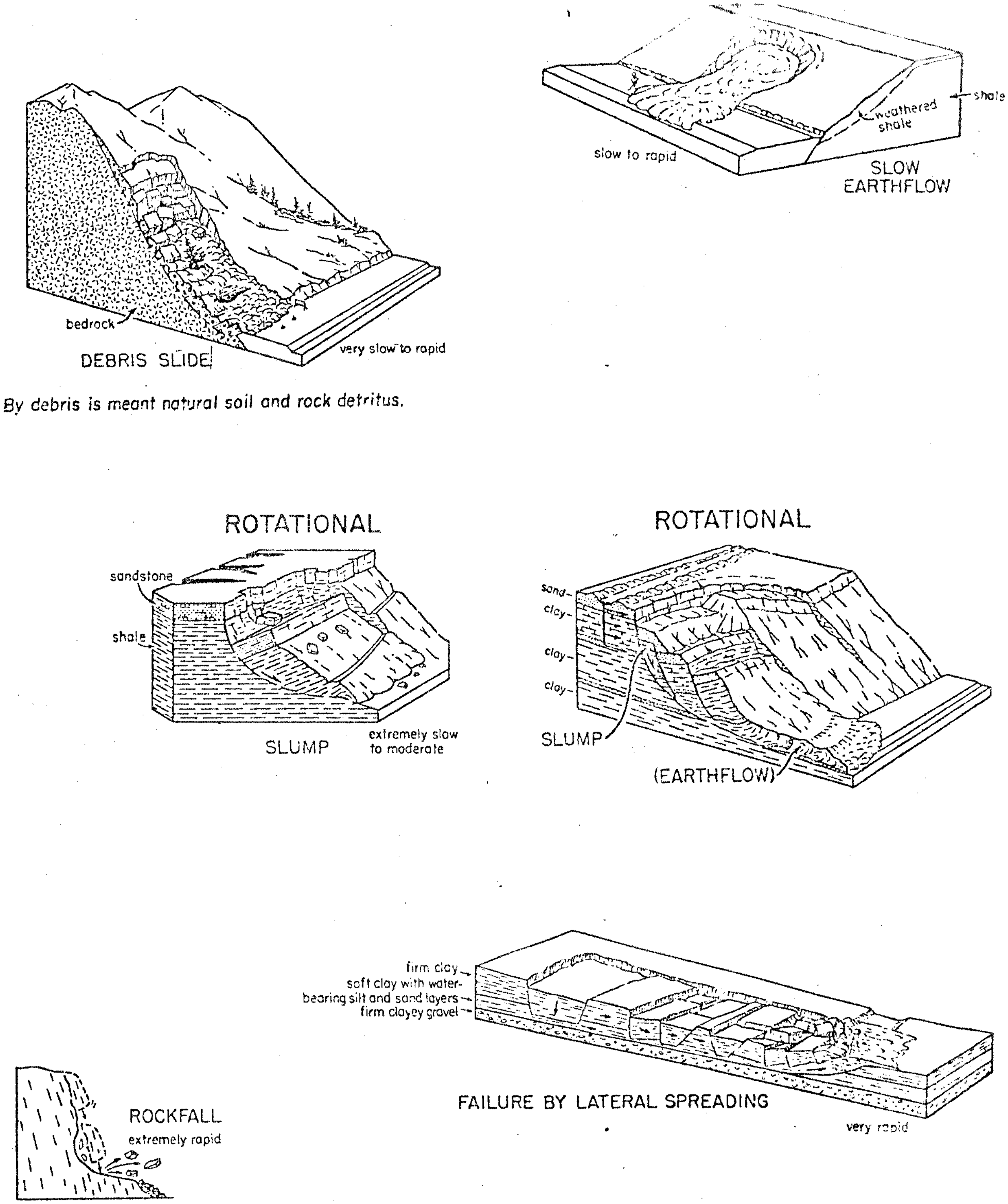
Landslides are classified according to the following criteria:

1. Mode of Movement
    - A. Fall--gravity falling, e.g., rockfall or soil fall (avalanche).

   B. Slide--movement along shear or fault planes, e.g., block glide or rotational slide (slump).
   C. Flow--viscous movement, e.g., debris slide, earthflow.
2. Type of material
   A. Soil
   B. Rock
   C. Combination
3. Rate of movement
   A. Rapid--avalanche, mudflow
   B. Slow--rotational block, block glide
4. Depth of movement
   A. Shallow--avalanche type, mudflow, debris
   B. Deep--rotational block

Numerous combinations of landslide classifications can be found in a single landslide area. Nearly all types of slides are found in this area and they range in size from minor slip-outs of few tens of square feet to huge slides of a square mile in surface area. Depth of landslides vary from a few feet to several hundreds of feet, depending upon the size and type (classification). Most of the large and significant slides noted in this study are the slow moving earth-rock debris slide or rotational earth (slump) slides. Slow movement may be sporadic and usually most of the movement occurs during the wetter months.

Earth-rock debris slides consist of incoherent or broken masses of rock and soil that move downslope by sliding or by

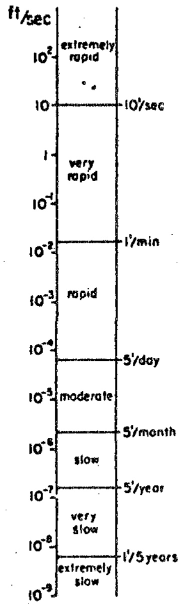


Illustrations from Erskine, 1973

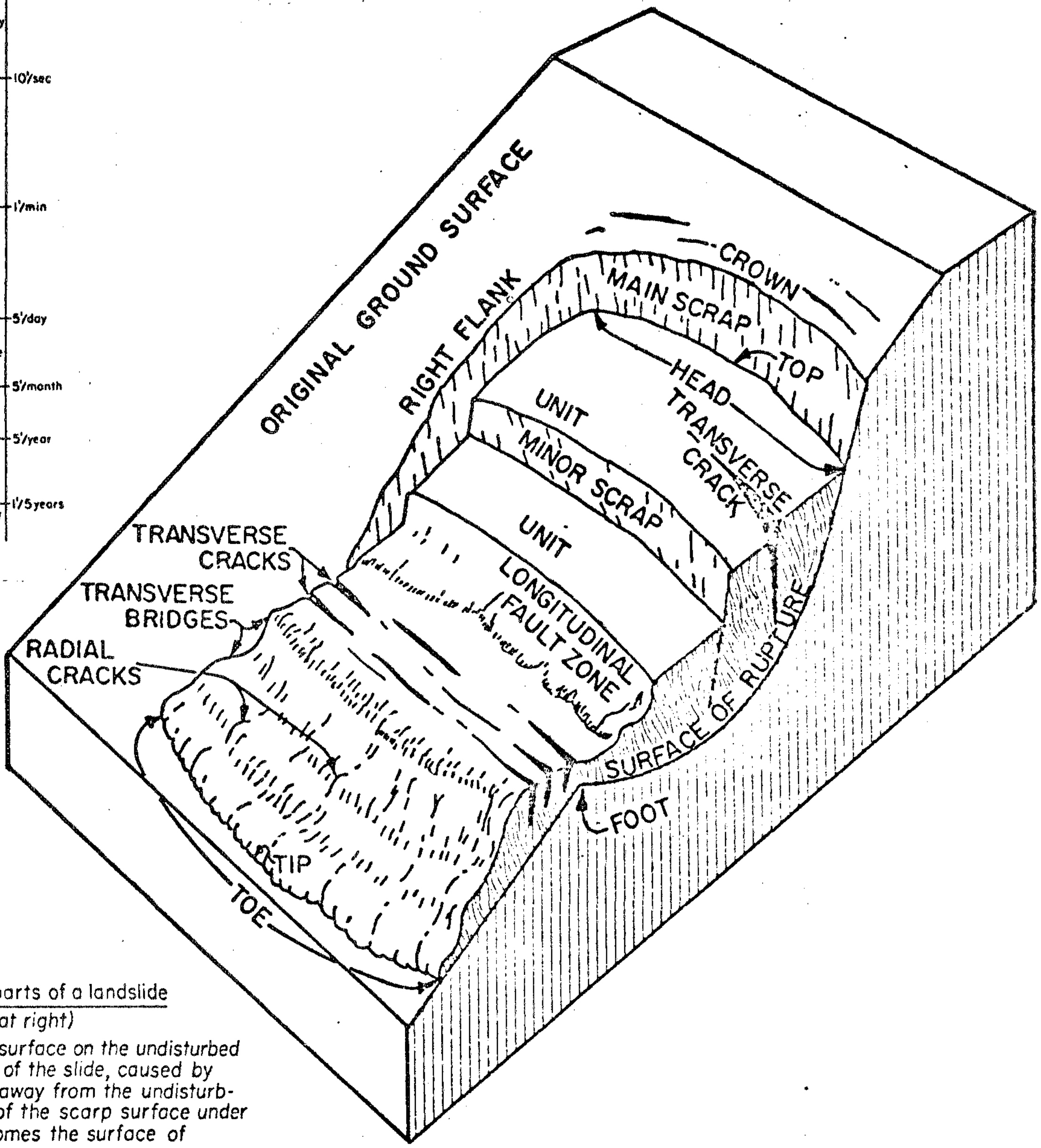
FREQUENTLY OCCURRING TYPES OF
LANDSLIDES IN STUDY AREA

Figure 2

Approximate ranges of rates of movement are according to the scale below



Landslide—*The term "landslide" denotes downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations thereof.*



Nomenclature of the parts of a landslide
(see drawing at right)

MAIN SCARP- A steep surface on the undisturbed ground around the periphery of the slide, caused by movement of slide material away from the undisturbed ground. The projection of the scarp surface under the disturbed material becomes the surface of rupture.

MINOR SCARP- A steep surface on the disturbed material produced by differential movements within the sliding mass.

HEAD- The upper parts of the slide material along the contact between the disturbed material and the main scarp.

TOP- The highest point of contact between the disturbed material and the main scarp.

FOOT- The line of intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.

TOE- The margin of disturbed material most distant from the main scarp.

TIP- The point on the toe most distant from the top of the slide.

FLANK- The side of the landslide.

CROWN- The material that is still in place, practically undisturbed, and adjacent to the highest parts of the main scarp.

ORIGINAL GROUND SURFACE- The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated.

LEFT AND RIGHT- Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown.

Illustrations from Erskine, 1973

LANDSLIDE NOMENCLATURE

viscous flow on a surface that underlies the deposit. These are usually triggered following periods of heavy rainfall.

Rotational earth slides consist of coherent or intact masses that move downslope by rotating along slip or shear surfaces that underlie as well as penetrate the landslide deposits.

Typical illustrations of the most common types of slides are presented on Figure 1. Landslide nomenclature is presented on Figure 2.

Landslides can also be classed as "active", "inactive" (old) or "possibly active". Active slides are those that are just forming, are continuing to move, or have moved recently and exhibit visible features indicating such recent movement (little doubt of concurrent or recent movement). Inactive slides are those that have temporarily stabilized and exhibit no surface features indicating recent movement. These are generally old or ancient slides. Possibly active slides are those where there is doubt as to their activity. If movement is occurring, it is so slow that the features that exhibit movement become masked or destroyed by erosion even as they are forming. Active, possibly active and inactive slides are all found within the County.

In recognizing landslides, a geologist depends a great deal upon the interpretation of stereo-paired aerial photographs as well as on field inspection, searching for landscape and geologic features which indicate the presence of a slide. In aerial photograph interpretation, typical characteristics of a slide include a semi-circular scar (main scarp in Figure 2) which outlines an amphitheater-like landform and a spoon-shaped area of disturbed ground with hummocky topography and undrained depressions. Disturbance of vegetative growth patterns may also provide clues. In the field, the most recent landslides are easily recognizable by the geologist by observing the characteristic features of landslides (as shown on Figures 1 and 2). In observing old or ancient landslides where the characteristic features have been modified by erosion and covered over by growth, a professional interpretation has to be made. Where the exactitude of an interpretation or the delineation of a known slide becomes critical, subsurface exploration such as drilling or geophysical testing would have to be performed to determine the presence of a slide and its activity and/or depth.

Geologic Processes and Causes of Landslides

The occurrence of landslides are related to the interplay of the inherent natural condition of the earthmass and geologic processes in motion. As discussed under "Geologic Setting", the susceptible formations or portions of formations posses "defects" and are inherently weak or soft, are deeply and intensely weathered, or intensely fractured, sheared or faulted. Sound, "competent" portions of formations are not as susceptible to sliding.

The geologic processes involved in causing landslides are in two general groups. On page 16 of the U.S. Geological Survey Professional Paper 675, Christopher F. Erskine (see bibliography, Erskine, 1973) discusses these processes as follows:

> "The causes of landslides are in two general groups: (1) basic processes which slowly reduce the stability of a mass of material and (2) trigger processes which in themselves are of minor importance but which, when added to the stresses already operating in a potential slide area, are sufficient to set the mass in motion. The trigger actions are more obvious and often are erroneously considered the dominant causes of slides. A trigger process, however, can start a landslide only after an area has become unstable through the operation of other factors. Eliminating possible trigger actions, nevertheless, can prevent or at least postpone many landslides."

The basic processes contributing to landslides are erosion and mass wasting. Erosion is the process whereby the land surface is being sculptured and worn down by rainfall and runoff. Mass wasting is a process whereby large masses of earth materials are moved by gravity, either slowly or quickly from one place to another.

The soil mantle, softer formations and weathered faulted and sheared zones of bedrock erode at a more rapid rate than stronger rock units, creating rugged, regular and irregular topography, typical of mountainous terrain in this area. Within a susceptible mass the modification of the land surface by erosion and mass wasting generates stresses in the mass making it potentially unstable by creating topographic features that makes the downward and outward movement of landslide possible. These basic processes where they interact with soft or defective formations are the principal cause of landslides. Removal of large masses of earth by man's activities can also serve as a basic process in the same manner.

The trigger processes, which provide the final impetus to set the previously stressed mass in motion, include further erosion, man-made cuts (both also serve as basic processes as previously discussed) and placement of fill, effects of groundwater and moisture absorption, and seismic shaking.

Erosion and man-made cuts serve as triggering processes by oversteepening a slope relative to its strength or by removing materials from the toe of a potential landslide which would otherwise hold back the slide by serving as a buttress. The placement of fill at the top or upper portion of a stressed slope can trigger landslide movement by adding weight which would further unbalance the soil mass.

The stability of slopes is greatly decreased by the presence of water in the earth mass, particularly on slopes consisting of soil. The water could come from groundwater and/or the absorption of water from rainfall, runoff, reservoir impoundment, irrigation, and/or septic tanks. Saturation of the earthmass can trigger landslides in various ways: (1) by decreasing the inherent soil strength by softening and lubricating it, (2) by causing a weight increase and a redistribution of weight within the soil mass, (3) by creating unfavorable internal seepage pressures (or forces) as the water slowly percolates downslope through the soil, and (4) by creating pore pressures or uniform hydrostatic pressures (as differentiated from seepage pressures) which cause a buoyant effect on the earth mass. As a consequence, most landslides are triggered during the winter and spring months when precipitation and groundwater are at their high.

Seismic ground shaking through imparting an acceleration force on a stressed slope has served as a trigger for many landslides. Ground shaking also magnifies the triggering effects imparted by groundwater, particularly by creating surges in the pore pressures within a soil mass. In some cases of seismic land shaking, lurch cracks have developed on the hillsides which then create incipient stage for the eventual development of slide movement.

Oftentimes, landslides are set in motion through the interaction of a combination of trigger processes. The relative effectiveness of each of the trigger processes may vary for a particular prevailing condition or may have varying influence depending upon the type of landslide. In some instances, the dominant trigger factor is difficult to appraise. Measures to be considered to prevent landslide movement or to minimize its effects would include the removal of the trigger mechanism or abating it as much as possible. Such measures would include erosion control, drainage controls, removal or interception of groundwater, and prudent design of cuts and fills.

Effects of Reservoir Construction Upon Geologic Processes

Construction of a reservoir imposes certain changed conditions. These include the impoundment of a large quantity of water over a long period of time, water level fluctuations due to reservoir operation and surface grading associated with the construction of the dam and appurtenances. These conditions have the following effects:

1. Sedimentation occurs and the erosional downcutting of the stream through the reservoir is halted.

2. Release of clearer waters from a reservoir into channels in alluvium may result in degradation (downcutting or more rapid stream erosion) downstream of the reservoir.

3. In areas where susceptible formations occur along the edges of the reservoir, new landslides may be triggered along and below the waterline as a result of saturation of the soil mass and as a result of reservoir drawdown. Once sliding is initiated, equilibrium is destroyed and new slides may continue several hundred feet upslope above the waterline. Landslides would not be induced as a result of reservoir operation where sound or unstressed rocks occur (masses unaffected by basic processes).

4. New movement may be triggered in once stable ancient landslides within and just upslope of the reservoir waterline. Although an ancient inactive landslide may have reached temporary equilibrium, the internal resistance within the mass is decreased due to saturation by the reservoir water and due to development of unfavorable internal seepage pressure as the reservoir water levels lower. Ancient inactive slides are more susceptible to reactivation than the initiation of new slides because they are generally less consolidated, have higher porosity and contain numerous weak shear planes, all of which are the result of previous movements.

5. Grading required for the construction of dam appurtenances which cut through hillside slopes and through existing

slides may trigger new slides and/or reactivate ancient slides. Such features related to reservoir construction include large-scale grading cuts for spillways, inlet and outlet approaches to dam outlet works, and access roads.

6. Soil creep within the reservoir may be accelerated due to reservoir drawdown.

Effects of Canal Construction Upon Geologic Processes

The District's canal system consists mostly of open, gunite-lined ditch with short segments of pipe, siphons, and flumes. The canals are small, usually less than 5 feet deep and 5 feet wide at the invert. Because a canal is a gravity flow system, the channel grade must be held constant and thus alignment is dictated by the topography. When a canal is constructed within a portion of the prevailing geologic setting, artificial conditions are imposed which may have the following affects:

1. Alignment inflexibility requires that construction be made in hillside slopes and through existing landslides. The cut-fill section redistributes loads within the slope. Existing slides can be reactivated and new slides triggered.

2. Alteration of subsurface drainage and modification of surface drainage with possible ponding, results in added infiltration into the earth mass which contributes to unfavorable hydrostatic conditions.

3. Saturation of the slope by leakage from the canal adds weight to the mass and results in unfavorable hydrostatic pressures.

4. The steep slopes in the cut section of the canal are prone to erosion and air slaking which can undermine the slope and trigger failure.

5. Rock units in cut sections are exposed to the atmosphere, which can result in accelerated weathering processes; this can weaken the rock unitl it has the characteristics of soil and increase the failure potential.

6. Soil creep may be accelerated due to steepened slopes.

EFFECTS OF LANDSLIDES

The following section briefly summarizes the more noteworthy existing difficulties landslides are causing. It also discusses the potentially disruptive and hazardous effects landslides can have on facilities and nearby improvements.

Present Effects of Landslides

1. Landslides along the peripheral edges of reservoirs and within the drainage area contribute large quantities of sediments to the reservoirs via surface runoff. This additional sediment production is due to erosion of bulked material, the softening of soils when they move, alteration of local drainage conditions, removal of vegetative cover, and disturbance of the natural surface case hardening or "pavement".

2. A landslide at the spillway of Coyote Dam is causing cracking, bulging, and disruption of the concrete lining. On one occasion, landslide materials avalanched into the spillway, partially damming it until removed.

3. An active landslide just upstream of Anderson Dam on the left abutment destroyed a portion of the boat launching ramp.

4. Active landslides or the reactivation of portions of older landslides have damaged road segments near the District's reservoirs, particularly at Guadalupe, Stevens Creek, and Anderson Reservoirs.

5. An active landslide or the reactivation of a portion of an older landslide has caused minor damage to a recreational

lakeside residence near Anderson Reservoir. Most of the damage occurred during the winter months of a particularly wet season (spring 1973).

6. Numerous landslides are present along District canals. Most are inactive, but some have become a maintenance problem during extremely wet years. However, encroachment by real estate development on lands adjacent to the canals, has resulted in grading and landscape irrigation in sloping areas downslope from the canal. This has unbalanced the slope and triggered some sliding.

Potential Effects of Landslides

Potential effects of landslides in connection with the reservoirs, in addition to the aggravation of the existing problems described in the foregoing section, include the following:

1. Slide movement may plug a reservoir outlet works by covering or damaging the structure at its inlet or outlet. Such a potential exists at Anderson Dam and possibly at Guadalupe and Calero Dams.

2. Slide movement may damage or dam the spillway structure, particularly at those sites where the depth of cut is large and in weak rock. This condition appears to exist at Coyote Dam.

3. A large rapidly moving avalanche could create, under certain special circumstances, a large wave in the reservoir which could overtop the dam, causing damage downstream. The potential for a large avalanche to occur would be limited to areas where slopes adjacent to the reservoir are excessively

steep for some distance upslope. In order for a large wave to be generated, the avalanche would have to occur into a deep portion of the reservoir. Other factors such as wave attenuation due to reservoir shape could also affect the results.

A large wave front could also be generated by a sudden release of a large quantity of water into the reservoir. This could result if a rapid avalanche temporarily dams the stream upstream of a reservoir and the water that had accumulated behind it was suddenly released into the reservoir by rapid destruction of the temporary dam by erosion. Also, the rising backwater behind the temporary avalanche dam would flood upstream lands. Areas particularly susceptible to rapid avalanching into upstream canyon areas are those located along active faults. The San Andreas fault zone lies upstream of Lexington and Stevens Creek Reservoirs and the Calaveras fault zone passes thru Coyote Reservoir and the upper portion of Anderson Reservoir. The triggering mechanism for such a large rapid avalanche would be ground shaking by a large earthquake. Temporary damming of the stream by a landslide occurred in the stream canyon upstream of the present Lexington Reservoir in the earthquake of 1906.

Large waves in the form of seiches can be generated by ground motion in a reservoir by large earthquakes without the occurrence of an avalanche. An example of such an event occurred at Hebgan Lake in Montana on August 17, 1959. A 20-foot high wave oscillated back and forth in the lake, overtopping the dam three times across its full 721-foot crest length by four feet (Christopherson, 1960).

Hazards to public safety and property due to generation of large waves in the reservoir would not be present unless the reservoir was full or nearly full during the event.

4. A large avalanche similar to the ones described above could also cause temporary damming of the stream canyon immediately downstream of an earthfull dam. The water thus backed up against the dam could result in dam and foundation stability problems if the temporarily impounded water is rapidly released, creating unfavorable seepage forces within the dam embankment and foundation. This hazard of temporary impoundment against the dam fill will be present only when there is a high uncontrolled discharge from the dam, e.g., spillway discharge when the reservoir is full.

5. The occurrence of a rapid landslide into a canal or across the canal causing failure of the canal could disrupt water service and result in water and mud damage to downslope property. In high density population areas or where real estate development is in proximity to the canal, such damage could be relatively extensive.

6. Development in areas up and downslope of the canals, could introduce septic tank discharge and water from landscape irrigation into the subgrade which could affect the stability of the slope.

Landslides not only could adversely affect District facilities and operation, but also pose a threat to public safety and all other improvements (roads, pipelines and other utilities, residential development, lakeside developments, recreational facilities, etc.). At this time, several applications for private lakeside recreational land development have been submitted for approval to the appropriate governmental agencies. In due time the pressures of private developments are expected to increase along with greater development of lakeside recreational areas and lands adjacent to the canals. Some proposals to mitigate the adverse and potentially hazardous conditions are covered under "Recommendations".

PERSPECTIVE ON CAUSES AND PREDICTION OF LANDSLIDES

As previously discussed under "Geologic Setting" the mountainous areas of Santa Clara County are particularly susceptible to landslides. This is due to the widespread occurrence of soft and variably weathered formations which are being progressively downcut and changed by natural erosion and mass-wasting processes. Landslide movements upon the resulting unstable slopes are triggered by oversteepening or undercutting through continued erosion, absorption of water, seismic shaking, and by man-made influences such as land grading, the introduction of water to the mass through irrigation, septic tank operation, and reservoir impoundment. Landslide activity in this area is and has been occuring as the natural outgrowth of these processes. It is therefore a foregone conclusion that this activity will continue into the future.

The state of the art for predicting the time when activity will be triggered at a specific location or condition is by no means exact. In general terms activity will be greater during the wetter months; they also can be initiated by ground shaking during a seismic event at any time of the year.

Under other circumstances, as it was pointed out under "Types and General Description of Landslides", the actual activity of some slides cannot be determined because if movement is occurring, it is at a slow, imperceptible rate. The activity of "possibly active" slides may be determined by installation of monitoring instruments (inclinometers, extensiometers) and periodic surveying of survey monuments. These types of monitoring would be practical only in the most critical and ominous slides. Another method, though less exacting, is to perform visual or photographic comparative inspections of the slide over periods of time. The geologic mapping (or documentation) of the landslides and logging of their descriptions performed for this study would serve as the reference point. In the event that any new slide problems arose within the reservoirs or that any slide may be involved in future controversy, comparative analysis can be performed as a result of the documentation for this study. Under such circumstances, differentation among the various possible triggering causes of the slide activity and the continuing activity status of the slide at a particular location in respect to time may become significant.

The potentially most catastrophic effect of a landslide would occur if it generated a large wave in the reservoir. For this to happen a combination of certain conditions must occur concurrently with an adverse physical setting. Such a setting and conditions would include a large unstable earth mass on steep slope adjacent to a deep portion of the reservoir, the occurrence of a large earthquake following periods of rainfall, resulting in triggering a large nearly instantaneous slide into a full or nearly full reservoir. The prediction of such eventualities cannot be made and the likelihood that two or more adverse conditions would occur concurrently is remote.

APPROACH TO STABILITY ANALYSIS OF LANDSLIDES OR LANDSLIDE POTENTIAL

Landslides occur when driving forces (gravity) acting on a mass exceeds the resisting forces (strength) of the mass along critical paths or arcs within the mass. When certain data are known or reasonably assumed, such as the subsurface configuration of the failure plane, strength of the material, weight of the sliding mass, depth to water and/or presence of seepage forces, the resistance to shearing (failure) can be determined. This allows a landslide to be analyzed by computing the driving and resisting forces to determine a relative factor of safety. A factor of safety below 1.0 means the driving force exceeds the resisting force and the mass is failing. A factor of safety exceeding 1.0 means the resisting force exceeds the driving force and a stable condition exists. The greater the deviation from 1.0, the greater the instability or stability. The driving and resisting forces are dynamic since they are affected by external factors such as effects of moisture introduced related to weather cycles and seismic conditions.

Formulas have been developed by which simple arc (rotational) failures, wedge (block) failures, and combination arc-wedge failures can be analyzed. In theory, any landslide or potential landslide can be analyzed. However, in most cases, the necessary data are quite difficult to obtain and, in many cases, some of the values are assumed or estimated. This is because most earth and rock masses in nature are heterogenous, and both the strength and weight values will vary. The subsurface configuration of a failure surface is rarely the smooth and symmetrical shape that is necessary for the mathematical formulas. Also, it is necessary to assume that the driving and resisting forces will be constant, whereas they are subject to change. Even with these limitations, if it is understood that the factor of safety values obtained are relative numbers, the mathematical analysis of landslides is a powerful tool and, when used with judgment, can give excellent results.

In most cases, because of the cost involved to obtain the necessary data, detailed analyses are only performed where landslides can affect or are affecting critical structures or improvements.

Improvement in the factor of safety of an existing landslide can be obtained by lowering the water table or hydrostatic head within the mass; balancing or removing excess loads; increasing the strength of the mass; or placing a buttress. Some old slides have achieved an improvement in the factor of safety by one or more of the mentioned conditions through natural processes. In some cases, these old slides may not move again for many hundreds of years, while others are just stable and could easily become active again. The use of "common sense" in regard to drainage, grading practices, and location of improvements will go a long way in reducing the potential for landsliding in many areas of the county.

SUMMARY AND CONCLUSIONS

1. Vast areas on the sloping hillsides of the Santa Cruz and Diablo Mountains, where the District's reservoirs are constructed, and foothill areas where the District's canals and other facilities are located, are underlain by formations susceptible to landsliding. These susceptible formations are soft and steeply sloping, sheared and faulted, deeply weathered or mantled by a variably deep soil cover.

2. Numerous small and large landslides have occurred in the study area as a result of the continuing natural processes of erosion and mass-wasting whereby the mountainous areas are being worn down. Differential erosion in the soft formations, along shear and fault zones in the bedrock formations, and of the soil mantle have created rugged and relatively steep slopes leading to instability. The instability condition resulting from these basic processes is the primary cause of landslides.

3. There are many triggering processes for landslide movement, after instability conditions exist. These include continued oversteepening or undercutting by the natural process of erosion, natural absorption of water by the soil mass from rainfall, runoff or rising groundwater, ground shaking by a seismic event, artificial land grading leading to oversteepening of the slope, or unbalancing by placement of fill on unstable slopes, and artificial introduction of water by irrigation, septic tanks, and reservoir impoundment.

4. Numerous small landslides along the peripheral edges of the reservoir have been triggered in defective or susceptible earth masses (a necessary antecedent condition) as a result of reservoir operation. Portions of ancient inactive landslides along the peripheral edges of the reservoirs have also been reactivated by reservoir operations.

5. Several major active faults pass through or are near some of the reservoirs. The San Andreas fault passes through the upstream portion of Lexington Reservoir and near Stevens Creek Reservoir and the Calaveras fault passes through Coyote Reservoir and the upstream (southern) portion of Anderson Reservoir. Other smaller, possibly active, faults also exist near several of the reservoirs. Earthquakes have been responsible for triggering new landslides as well as reactivating portions of older slides within the study area.

6. Landslides range in age from ancient to recent and can be classed as active, inactive, or possibly active. Active slides are those that are moving or have recently moved while inactive slides have reached temporary equilibrium and recent movement has not occurred within them. Portions of older inactive slides may become active when the local equilibrium conditions are changed by natural or by man-made activities. Possibly active slides are those in which there is doubt as to their activity and evidence for recent movement is not clear.

7. In numerous ways landslides present and have the potential to present hazards to public safety, to District facilities and their operations, and to other public and private

developments and improvements. For the potentially most catastrophic effects of landslides to occur in connection with reservoir operations, a combination of certain conditions must come into play concurrently and, thus, the resulting risks for such an event are vastly reduced.

8. The documentation of existing landslides and their conditions, accomplished as part of this study, provides a basis for assessing hazards to existing structures and future improvements. It also provides a basis for future comparative analysis in order to determine the activity of the landslides so that a better assessment can be made of the real or potential hazard. Documentation for comparative purposes may also provide an important reference in the event of future controversy arising out of reservoir and canal operations affecting local improvements. Instrumentation and surface monitoring surveys performed on several landslides at Anderson Reservoir provide more explicit documentation of conditions occurring in these slide areas.

RECOMMENDATIONS

1. Periodic geologic inspections and reviews of the areas around District facilities should be performed to document new slides, if any, and to determine changes of conditions regarding existing slides. In this manner an up-to-date hazards evaluation will be available. Additionally, documentation of existing conditions will be available in the event of controversy which may arise regarding damages to improvements as possibly being caused either by reservoir or canal operations or by other natural or man-made causes.

2. This study should be made available to public agencies and private developers whose realm of interest lies within the study areas in order to point out current geologic conditions and potential hazards and to provide a perspective for the causes and possible effects of the hazards.

3. Various geologic hazards do occur within the reservoir watershed areas and in the face of increasing pressures to develop recreational land use projects within these areas, the District should adopt a policy that assures that all proposed improvements will be thoroughly investigated in order to assess the geologic hazards and risks involved. This would include determining geologic conditions at the site, the natural geologic processes in motion, and the alteration of conditions imposed by existing and proposed improvements. This policy would be in the interest of promoting public safety and protection of all individuals, properties, and improvements including those

of the District. This policy should be forwarded to appropriate public agencies and the District should be given the opportunity to review applications and geologic studies for future developments in the reservoir areas and along canals.

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GLOSSARY OF SELECTED TECHNICAL TERMS

Alluvial - Pertaining to alluvium.

Alluvium - Recent unconsolidated stream deposits in the form of clays, sands, gravels, peat, etc.

Altered or Alteration - Change in the chemical and mineralogical composition of a rock, typically brought about by the action of hydrothermal solutions.

Anticline - Beds arched so as to incline away from each other.

Basalt - An extrusive igneous rock (volcanic), fine-grained and dark colored.

Berryessa Formation - An assemblage of unmetamorphosed sedimentary rocks found along the lower western flank of the Diablo Range adjacent to Santa Clara Valley.

Claystone - Indurated clay.

Chert - A siliceous rock formed of chalcedonic or opaline silica. Commonly found in the Franciscan Formation.

Cohesion - The capacity of sticking or adhering together; that part of shear strength which does not depend upon interparticle friction.

Colluvial - A term applied to deposits which usually occur at the foot of a slope and which consist in part of alluvium and angular fragments brought downslope by the action of gravity.

Conglomerate - A sedimentary rock consisting mostly of cemented and rounded gravel sized clasts.

Cretaceous - A time period to 135 million years ago.

Diabase -Intrusive igneous rock of basaltic composition.

Dip - The angle at which any stratum or any other planar feature is inclined from the horizontal.

Excessive Erosion - More than normal erosion, such as in cases where "bad land", topography is formed.

Expansive Clay - Clay which exhibits the property to absort water and swell or expand. The clay type is usually bentonite (clay mineral montmorillonite). "Adobe" soils usually have expansive properties.

Franciscan Formation - An assemblage of diverse, generally slightly metamorphosed, highly faulted and folded rocks of Late Jurassic and Cretaceous age.

Gouge - A layer or zone of soft finely abraded material occurring along a fault. The result of crushing along the fault.

Graywacke - Sandstone-like rocks of a prevailing gray color marked by large detrital quartz and feldspar fragments set in a dominant clay matrix.

Greenstone - Low metamorphic grade basic igneous rocks generally containing the greenish minerals chlorite, hornblende and epidote.

Holocene - A time division of the Quaternary Period; recent time (current time to 10,000 years ago).

Hydrostatic Head - The level that water would rise in a tube when placed into a saturated medium having water under pressure.

Indurated - Hardening of rocks by heat, pressure and cementation.

Intrusive - A rock unit which has been forced, in a molten or semi-molten state, into another rock body.

Joint - A fracture which interrupts abruptly the physical continuity of a rock mass.

Jurassic - A time period 181 to 135 million years ago.

Lenticular - More or less lens-shaped. Generally a rock which thins out from the center to thin terminal ends.

Limestone - A sedimentary deposit consisting chiefly of calcium carbonate.

Mafic - Basic composition, dark minerals.

Metamorphism - A change in texture or mineralogy of a rock after its induration or solidification. Produced mainly by heat and pressure.

Miocene - A time division of the Tertiary Period 25 to 13 million years ago.

Oligocene - A time division between 25 and 36 million years ago.

Packwood Formation - A formation found on the east side of Santa Clara Valley in southern Santa Clara County and composed of semi-consolidated fluvial deposits of gravel, sand, silt and clay.

Plicated - Folded together as in highly inclined and contorted strata.

Pleistocene - A time division of the Quaternary Period 10,000 to 1,000,000 years ago.

Pliocene - A time division of the Tertiary Period 13 to 1 million years ago.

Pore Pressure - Interstitial water pressure, developed by hydraulic head or by application of load to the containing medium.

Quaternary - A time period from the present time to one million years ago.

Sandstone - Cemented detrital sediment composed predominantly of quartz grains.

Santa Clara Formation - An older alluvial semi-consolidated formation of Pliocene to Pleistocene in age. Occurs along much of the periphery of Santa Clara Valley and underlies much of the valley at depth.

Seepage Forces - Movement of water through a mass where the neutral stress (excess water pressure) may change the strength or condition of a mass.

Serpentine(ite) - A rock consisting almost wholly of serpentine minerals derived from the alteration of previously existing olivine and pyroxene.

Shale - A laminated sedimentary rock in which the principal constituent particles are predominantly of clay size.

Shear Strength - A combination of cohesion and interparticle friction values that resist shearing.

Silica-Carbonate Rock - A hydrothermally altered serpentine rock composed principally of silica and a carbonate.

Siltstone - Consolidated clastic rock composed predominantly of particles of silt grade.

Slaking - The disintegration of soil or rock when exposed to air or moisture.

Strike - The direction or bearing of a horizontal line in the plane or an inclined stratum, joint, fault or other structural plane.

Syncline - A trough-like fold in the strata of rocks.

Tectonic - Rock structure and external forms resulting from the deformation of the earth's crust.

Terrace Deposits - Generally unconsolidated flat-lying older alluvial deposits which occur at a higher elevation than the younger alluvium.

Tertiary - A time period 1 to 65 million years ago.

Tuff - Rock formed of compacted volcanic fragments (generally ash size material).

Ultrabasic Intrusive - An intrusive rock with minor silica content. Includes serpentinite and other basic igneous rocks.

Volcanics - Class of igneous rock that have been poured out or ejected (extruded) at or near the earth's surface.

Weathered or Weathering - Group of processes, such as chemical action of air and rain water and of plants, bacteria, and mechanical action of changes in temperature that causes decay and decomposition.

NOTE: Some definitions adapted from "Glossary of Geology and Related Sciences" the American Geological Institute, National Academy of Sciences, Washington, D.C. 1957.